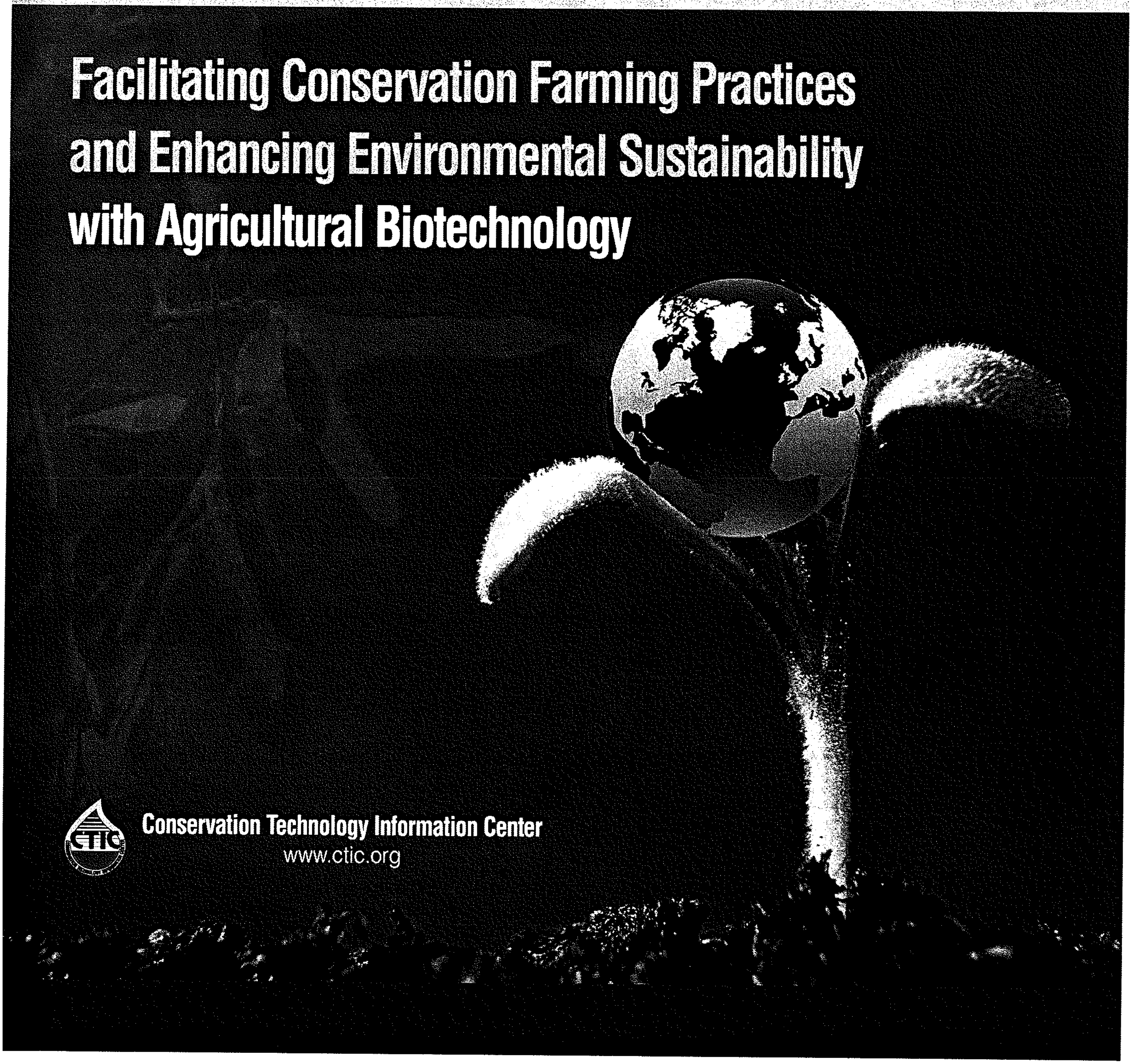
E

Facilitating Conservation Farming Practices and Enhancing Environmental Sustainability with Agricultural Biotechnology



Conservation Technology Information Center
www.ctic.org

Facilitating Conservation Farming Practices and Enhancing Environmental Sustainability with Agricultural Biotechnology

by

Dan Towery *Ag Conservation Solutions, LLC*

Steve Werblow *Conservation Technology Information Center*

Table of Contents

ISBN 978-0-9822440-1-2

 PUBLISHED BY THE CONSERVATION TECHNOLOGY INFORMATION CENTER

The Conservation Technology Information Center (CTIC) is a national, nonprofit 501(c)(3) organization. CTIC champions, promotes and provides information about comprehensive conservation and sustainable agricultural systems that are beneficial for soil, water, air and wildlife resources and are productive and profitable for agriculture.

This publication was made possible through funding provided by the United Soybean Board (USB) Sustainability Initiative. USB is made up of 68 farmer-directors who oversee the investments of the soybean checkoff on behalf of all U.S. soybean farmers. Checkoff funds are invested in the areas of animal utilization, human utilization, industrial utilization, industry relations, market access and supply. As stipulated in the Soybean Promotion, Research and Consumer Information Act, USDA's Agricultural Marketing Service has oversight responsibilities for USB and the soybean checkoff. The opinions expressed are those of the authors based on a comprehensive review of the published literature.

REVIEWERS

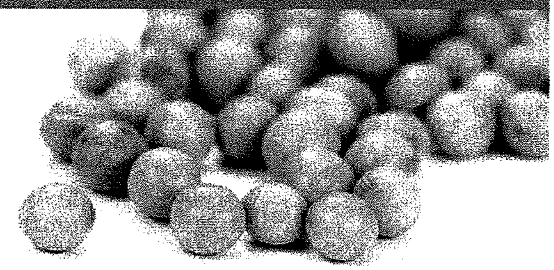
Dr. Shaun Casteel *Purdue University*

Dr. Jerry Hatfield *National Laboratory for Agriculture and the Environment*

Dr. Richard Joost *United Soybean Board*

Dr. Hans Kok *Conservation Cropping Systems Initiative*

James W. Pollack *Environmental consultant, Omni Tech Int'l., Ltd.*



Introduction

Today's farmers are under unprecedented pressure. The world's population is closing in on seven billion, and it is projected to reach nine billion by 2050. Billions of those people will be enjoying an improving standard of living, including increased consumption of more nutritious food, milk, meat and energy.

A crowded planet adds to the environmental challenges of feeding, clothing and powering the world. Water supplies will be increasingly scarce, threatened by pollution, and diverted to population centers. We can no longer set out to farm new frontiers – we must make every acre already being farmed even more productive and prevent environmental degradation.

With shrinking resources and little margin for expansion, the stakes of environmental degradation are too high. Protecting our soils, air and water – and our forests, wetlands and grasslands – is vital to all of us in the long term. Environmental and economic sustainability are essential on every farm.

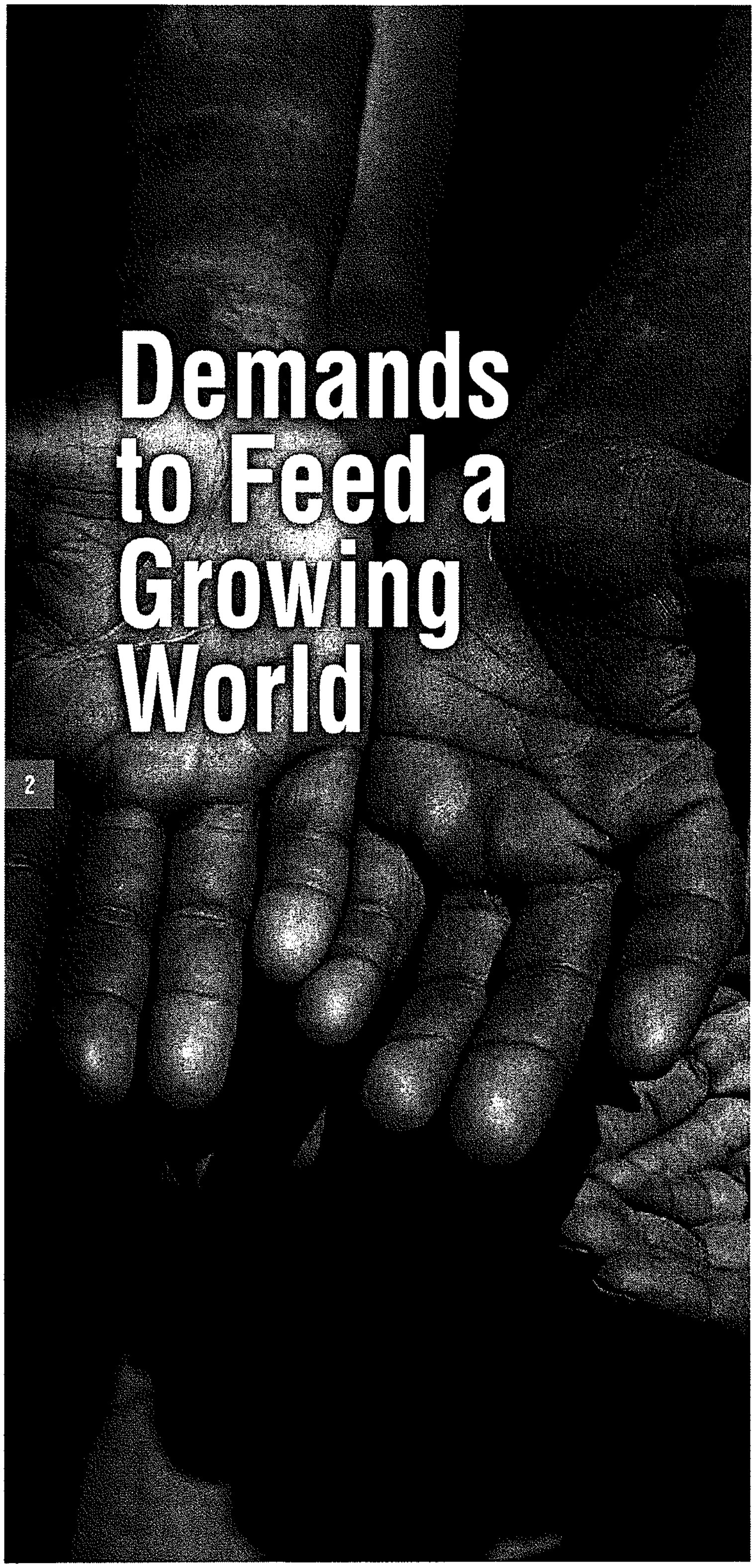
Norman Borlaug, the legendary plant breeder and Nobel laureate who was the driving force behind the Green Revolution of the 1960s and 1970s, summed up the task when he wrote, "Over the next 50 years, the world's farmers and ranchers will be called upon to produce more food than has been produced in the past 10,000 years combined, and to do so in environmentally sustainable ways" (Matz, 2009).

The American farmer is uniquely prepared to meet the challenge of feeding a growing world. Pioneer spirit, hard work and grit are complemented by tools, technology and management. Together, they allow U.S. farmers to feed more people with every acre. Among those tools is plant biotechnology, which is already enabling growers to feed more people, with less land and chemicals, than ever before. As the pressure on farmers grows, agricultural biotechnology is on its way to becoming the most revolutionary life-saving technology the world has ever seen.

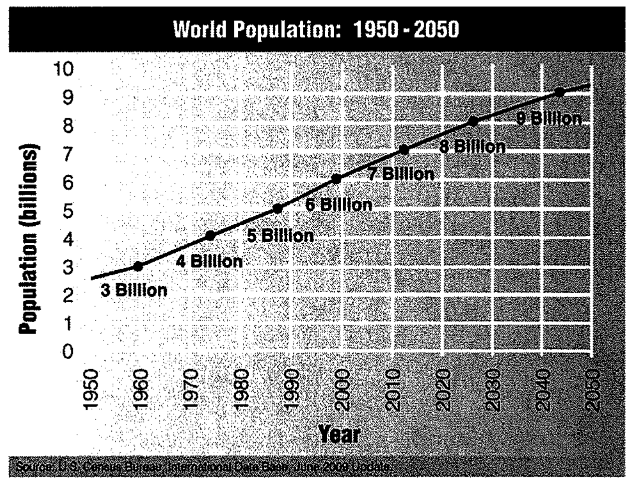
Soybeans have already enriched countless lives around the world through the protein and oils they provide directly to human diets, as well as nutrition for livestock and a sustainable biofuel feedstock. Soybeans have been among the first crops targeted for many advances in biotechnology. In addition to direct production improvements including improved pest control options, biotech soybeans have facilitated farmers' adoption of a variety of sustainable farming practices, including conservation tillage – in which high-disturbance tools are replaced by tillage tools that cause less soil disturbance and leave more crop residue on the soil surface – or no-till farming, in which the soil is undisturbed except for placing the seed into a narrow seedbed.

In this document, we will explore how plant biotechnology and the sustainable farming systems it helps facilitate – in soybeans as well as in other crops – are helping farmers grow more food, feed, fiber and fuel while protecting the environment.

Demands to Feed a Growing World



The earth's population is growing at a steadily increasing rate. It took the human race until the turn of the 19th century to reach a population of 1 billion, and the 20th century dawned on a population of 1.65 billion (Daigger, 2009). By 2000, the global population was roughly 6 billion, and the U.S. Census Bureau projects that it will top more than 9 billion by about 2050. That increase alone is equal to the entire world population in 1950 (UN Population Fund, 2008).



Source: U.S. Census Bureau, International Data Base, June 2009 Update.

Rapid population growth is the result of a variety of factors. High fertility is, of course, a primary one. But so are lower mortality, greater life expectancy and an age curve that skews increasingly toward a younger population – billions of people of childbearing age (UN Population Fund, 2008).

As the population increases by 50 percent in less than a half-century, the standard of living in many areas of the globe is also expected to steadily increase. In fact, Daigger (2009) estimates that if current consumption trends do not change in the 21st century, growing demand for improved diets, combined with the increasing population, will create three times the current pressure on the earth's resources.

As living standards rise for many people in the developing world, others remain mired in poverty. According to the Food and Agriculture Organization of the United Nations (FAO), 854 million people, or 12.6 percent of the global population, were malnourished in 2006 (FAO, 2006). Malnutrition, also called undernourished, plays a role in at least half of the 10.9 million child deaths each year, exacerbating the effects of diseases ranging from malaria to measles, according to the World Hunger Education Service (2009).

Room for New Farms?

Expanding the global cropland base could increase world food production, but even an expansion in acreage must be accompanied by steady improvements in yields to keep pace with the growing population. Peter Goldsmith, executive director of the National Soybean Research Laboratory at the University of Illinois, estimates that to meet the food and feed demands of the projected human population in 2030, growers would have to add 168 million acres of soybeans to existing production levels if world yields remained at the current average of 34.2 bushels per acre, or plant an additional 118 million acres if yield increases continued along their current trend and reached 38.6 bushels per acre. To supply enough soybeans projected under the scenario without increasing acreage, yields would have to nearly double to 59.5 bushels per acre (Goldsmith, 2009).

Meanwhile, the environmental costs of bringing new land into crop production are under increasing scrutiny. Most of the world's remaining arable land is in South America and Africa. On a significant amount of that land, soils and climate may be considered marginal for sustainable farming. Clearing new land for agriculture could also lead to the loss of valuable forests and other ecosystems, which could impact the global climate system (Costa and Foley, 2000) or contribute to desertification (Reich et al., 2001).

Global climate change is predicted to result in more extreme weather events – instead of a relatively steady cycle of moderate rain and dry periods, many areas of the world are expected to experience drier droughts punctuated by more severe storms. That variability from year to year would add uncertainty to global food supplies, world economics, farmer profitability around the world and future land-use decision making. Those effects would be felt first, and most dramatically, where farmers bring marginal land into production or farm in regions already prone to extensive droughts or storm damage.

U.S. Trends Track Global Ones

Trends in the U.S. are expected to parallel the world population curve – demographers expect a 50-percent increase in the U.S. population by 2050, a total of 450 million people (Daigger, 2009). Meanwhile, cropland acreage in the U.S. has decreased slightly over the past 60 years, and pasture/grassland acreage has also been declining (Lubowski et al., 2006). Today, American farmers produce annual crops on about 20 percent of the nation's land area, and raise forage or grazing livestock on another 26 percent (Lubowski et al., 2006).

Among the most versatile and nutritious crops produced by U.S. growers are soybeans. High in protein, rich in oil, and versatile enough to be consumed directly or fed to livestock, soybeans are a key component in diets around the world. With improvements in productivity and crop characteristics – many made possible through agricultural biotechnology – soybeans will remain a mainstay of diets in both developed and developing countries as the population continues to grow.

Breakthroughs in Agricultural Biotechnology

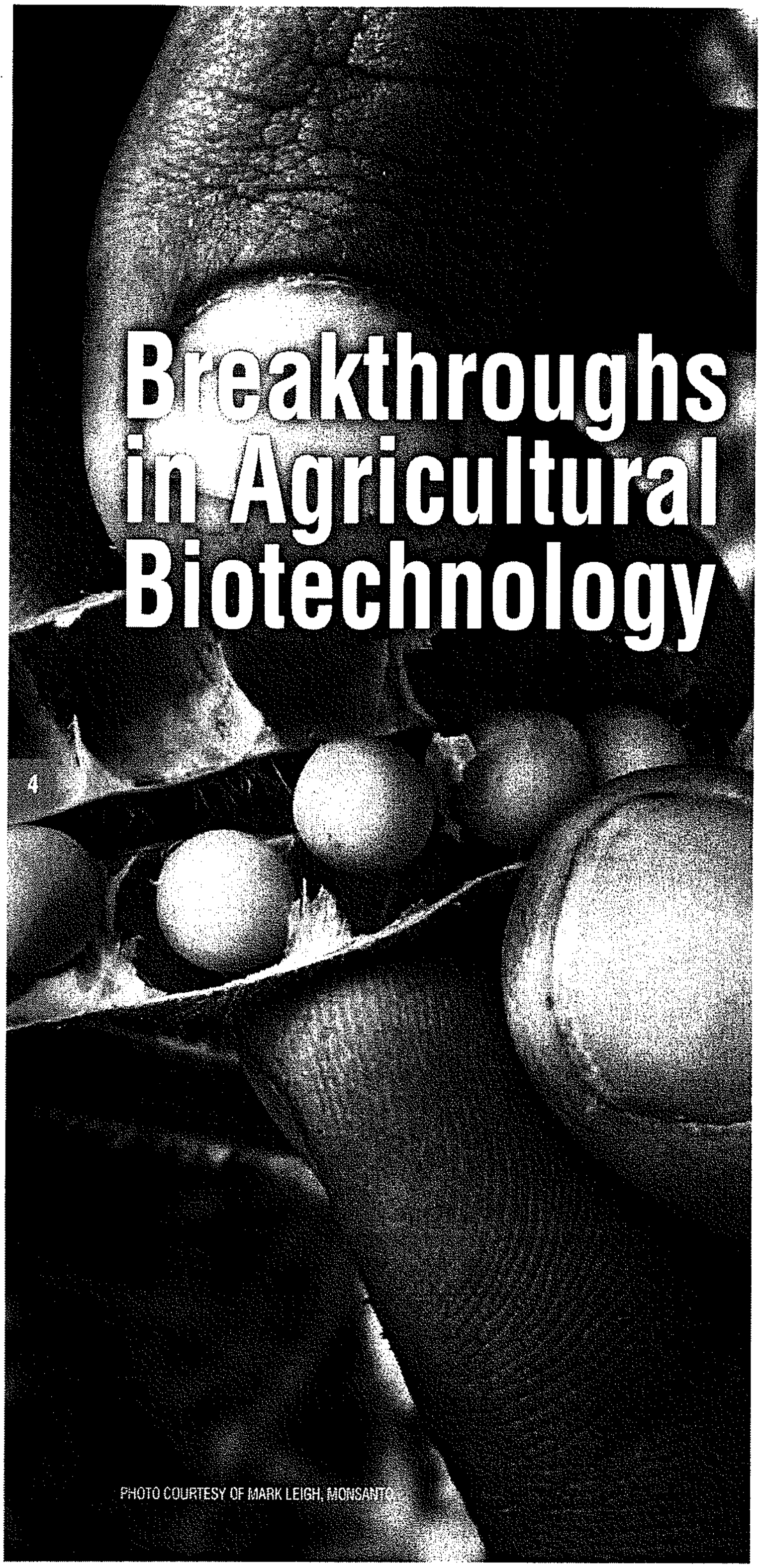


PHOTO COURTESY OF MARK LEIGH, MONSANTO

The term "biotechnology" was coined early in the 20th century, but the practice – using living organisms to produce other materials or perform specific industrial tasks – dates back thousands of years. Harnessing yeast to make bread and wine, or using rennet to turn milk into cheese, are ancient examples of biotechnology. That basic principle endures today: pharmaceutical companies use microorganisms to create antibiotics and a host of other important medicines.

Biotechnology has also modernized. It is at the heart of processes like DNA fingerprinting, which uses enzymes to reveal patterns in genetic material. Biosensors can instantly detect *E. coli* bacteria in food samples. Biotechnology also permits marker-assisted breeding, which allows breeders to "peek" into the genetic material of their crosses to quickly determine whether plants contain key traits – an advance that speeds the breeding process dramatically and has nearly doubled the rate of yield gain compared to conventional breeding techniques (Monsanto, 2009).

In this paper, the terms "biotech crops" and "biotechnology-derived" crops refer to plant cultivars that have been modified using biotechnology tools such as genetic transformation – the movement of specific genes from one source to another.

Commercial Introduction

In 1996, Monsanto introduced two biotechnology breakthroughs in the U.S. – Roundup Ready® soybeans and Bollgard® cotton, the first commercially released biotech-derived row crops.

Roundup Ready soybeans are elite lines of soybeans that have been transformed to include a gene that allows them to produce an enzyme system in their growing points that is not susceptible to disruption by glyphosate, the active ingredient in Roundup® herbicide. Planting a soybean variety tolerant to glyphosate allows growers to apply the herbicide – which is relatively inexpensive, extremely low in toxicity to humans and animals, environmentally benign and extremely effective at controlling more than a hundred species of weeds – without risk of killing their crop (Monsanto, 2007).

Bollgard cotton varieties and Bt corn hybrids include a gene from a bacterium called *Bacillus thuringiensis*, or Bt, that causes the plant to produce an insecticidal protein. *B. thuringiensis* can produce different crystalline proteins that vary in their efficacy on specific insect species. Ingested by a susceptible insect pest, the crystal dissolves, releasing its endotoxins, which are in turn activated by enzymes in the insect's digestive system. The activated toxin perforates the insect's gut wall, killing the target pest through starvation or a secondary infection (Witkowski, 2002). By harnessing Bt, which can also be sprayed onto crops as an organic insecticide, growers who planted the modified crops immediately reduced their use of insecticide sprays dramatically.

Subsequent commercial releases built on early successes. Roundup Ready canola, which was released in Canada in 1996, entered the U.S. in 2000. In 2008, Roundup Ready sugar beets were introduced in the U.S. The following year, Monsanto released Roundup Ready 2 Yield varieties of soybeans, which contain a second-generation trait for glyphosate tolerance. The company says the new varieties have the potential to deliver yields 7 to 11 percent higher than first-generation Roundup Ready soybeans, and are a stepping stone to achieving Monsanto's goal of doubling yields in soybeans, corn and cotton by 2030 (Monsanto, 2008).

U.S. growers also had their first opportunity to grow Liberty Link® soybean varieties in 2009, which contain a gene that conveys tolerance to glufosinate, the active ingredient in Bayer's Liberty® and Ignite® herbicides, broad-spectrum alternatives to glyphosate.

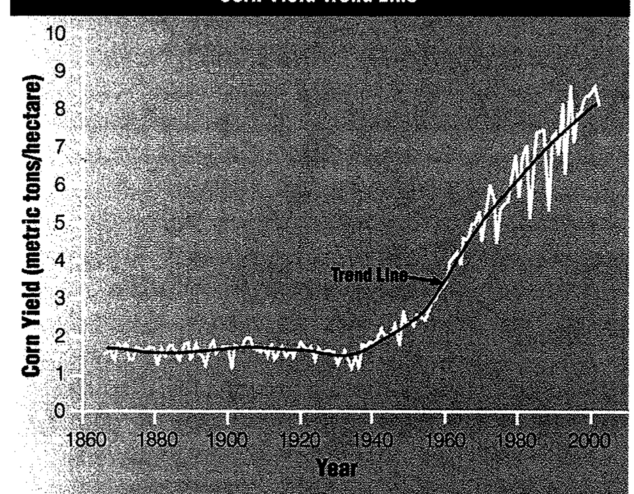
Stacked Varieties Combine Benefits

Improvements in genetic engineering capabilities have also allowed breeders to combine traits in elite crop varieties, "stacking" genes for both insect and herbicide tolerance in the same plants. Stacked varieties simplify management and reduce risk on several fronts at once.

Three-way stacks in corn – for instance, hybrid packages that combine a gene for a Bt protein aimed at European corn borer, a gene for another Bt protein geared toward protection from corn rootworm and herbicide tolerance in the same hybrids – are not uncommon. A partnership between Monsanto and Dow AgroSciences has developed a remarkable eight-way stack that delivers multiple modes of action against several insect pests as well as the opportunity for growers to choose among key herbicides for efficient weed control.

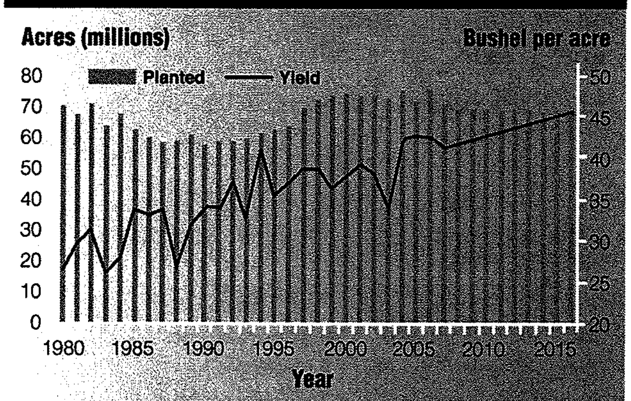
Huffman (2009) points out that stacked hybrids are likely to double or triple the rate of yield increase in corn. Rather than the two-bushel-per-acre average annual increase that has been achieved since 1955, breeders have targeted a rate of increase of four to six bushels per acre per year between now and 2019. Over the past 50 years, soybean productivity has improved by an average of 0.5 bushels per acre per year; Huffman predicts biotechnology will match or exceed that rate of improvement (Huffman, 2009). Monsanto and Syngenta project drought-tolerant hybrids in development will add 8 to 10 percent yield in corn.

Corn Yield Trend Line



Source: International Service for the Acquisition of Agri-Biotech Applications (James, 2008)

U.S. Soybean Acres and Yield



Source: USDA Agricultural Baseline Projections to 2016 (USDA ERS, 2007). USDA, Economic Research Service

The Next Generation of Biotech Crops

The direct benefits of the first generation of biotechnology-derived crops lay largely in production efficiencies – easier, more effective pest control. Part of the reason is that introducing a gene that produces a single protein is much simpler than transforming a crop with multiple genes to address more complex challenges such as nutrient content or stress tolerance.

Ironically, the success of the first generation of biotech crops fueled some opposition to plant biotechnology. Though the rapid embrace of biotechnology by the pharmaceutical industry – where it was harnessed to design, improve and produce a variety of medicines, including insulin – raised little or no consumer suspicion, biotech crops have stimulated heated public debate in many areas.

As a result, the commercial release of some biotech crops has been challenged, and sometimes delayed. In some cases, the impetus came from consumers, such as the 2009 lawsuit – the second year Roundup Ready sugar beets were planted commercially – in which a U.S. District Court judge ruled that Monsanto had to complete an environmental impact statement on the crop (Pollack, 2009). In other cases, such as with bioengineered wheat and potatoes, many farmers and large food retailers resisted the commercialization of the crops, afraid that frightened consumers, especially in export markets, would close their doors on biotech staples.

Much of the anti-biotech debate highlights the fact that some shoppers are wary of input traits that benefit farmers without a direct payoff for consumers. Also, they may not consider indirect benefits such as lower food prices, less use of crop protection products and better conservation practices that protect soil, water and air resources. However, a new wave of biotech crops may offer consumers more benefits to which they can relate directly.

The next generation of biotechnology will be focused on output traits, or consumer attributes, including:

- Soybeans whose oil contains less linolenic acid and more oleic acid, which improves heat stability without producing trans fats that have been implicated in coronary disease;
- Soybeans with lower levels of saturated fat and high levels of unsaturated oleic acid, for a health profile akin to olive oil;
- Soybeans high in heart-healthy Omega 3 fatty acids, such as stearidonic acid;
- Food ingredients in which the major allergens are modified or eliminated;
- "Golden rice," which produces beta-carotene in its endosperm. Beta-carotene, the carotenoid that stimulates the production of Vitamin A, is typically produced in the green tissues of riceplants, but is ordinarily not consumed (Golden Rice Humanitarian Board, 2009). Vitamin A deficiency blinds more than 500,000 children and kills more than 2 million people per year, according to the World Health Organization (Dobson, 2000);
- Crops that can be converted more efficiently into biofuels, such as readily fermentable corn.

Additional input traits are also being developed or commercially introduced, including:

- High-yielding soybeans capable of 7-to-11-percent increases in yield potential;

- Resistance to a wider range of herbicides;
- Bt soybeans with built-in protection against caterpillars such as soybean loopers, an innovation most likely to be introduced in South America, where caterpillar pests are a more significant problem than they are in the U.S.;
- Soybeans with built-in resistance to soybean cyst nematode, the most economically damaging disease in U.S. soybean production, estimated to have reduced the U.S. soybean crop by nearly 2 million metric tons in 2005 (Wrather and Koenning, 2009);
- Crops that utilize nitrogen or water more efficiently, which allows them to produce food and fiber with less applied fertilizer and irrigation – an advance that could not only reduce production costs, but could also improve water quality;
- Wheat tolerant to the devastating *Fusarium* fungus;
- Rice tolerant to herbicides and insects;
- Plants that tolerate poor soils, such as saline soils or those with low fertility or high levels of phytotoxic elements.

Many of these second-generation traits reflect huge advances in scientists' ability to unlock the genetic code and identify the genes – often several genes scattered about the DNA of donor plants – that can confer these important abilities. Moving bigger parcels of genetic material and screening offspring for commercial performance represent remarkable achievements in the science and art of breeding.

With the advent of more biotech-derived varieties featuring output traits, the benefits of agricultural biotechnology will be even more directly appealing to consumers around the world, and even more important tools for improving crop quality, human health and food security.

High Adoption of Biotechnology

Growers immediately recognized the benefits of biotech crops. The new genes offered the opportunity to fight pests with safer tools, make crop management simpler, and apply less pesticide. As a result, farmers enthusiastically planted biotech seed in the mid '90s.

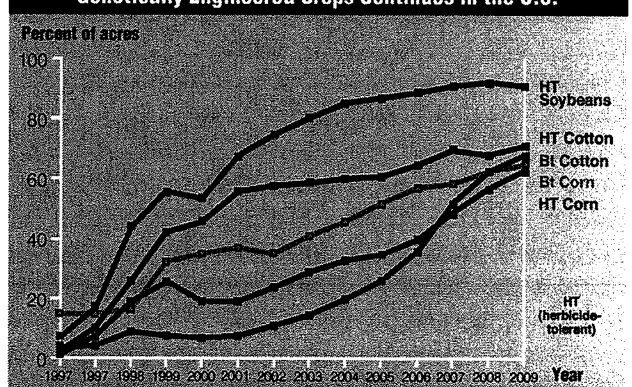
Worldwide, biotech crop acreage has been increasing at a steady rate of more than 10 percent each year since the turn of the 21st century; today, more than 13 million farmers in 25 countries plant biotechnology-derived crops (James, 2008). James estimates the economic benefits of biotech totaled more than $44 billion between 1996 and 2007, the result of both yield gains and reduced production costs attributed to biotech varieties (James, 2008). Abdalla et al. (2003) predict the full global adoption of biotech crops would result in income gains of $210 billion per year for farmers – and that some of the greatest gains are expected to occur in developing countries.

Biotech crops already dominate key U.S. crops. By 2009, 91.5 percent of the U.S. soybean crop, 85 percent of the nation's corn crop and 88 percent of the country's cotton acreage were planted to biotech varieties (Fernandez-Cornejo, 2009).

Of the 88 percent of the U.S. cotton crop planted to biotech varieties in 2009, 17 percent was planted to Bt cotton, 23 percent to herbicide-tolerant varieties and 48 percent planted to stacked varieties that combine Bt and herbicide tolerance (Fernandez-Cornejo, 2009).

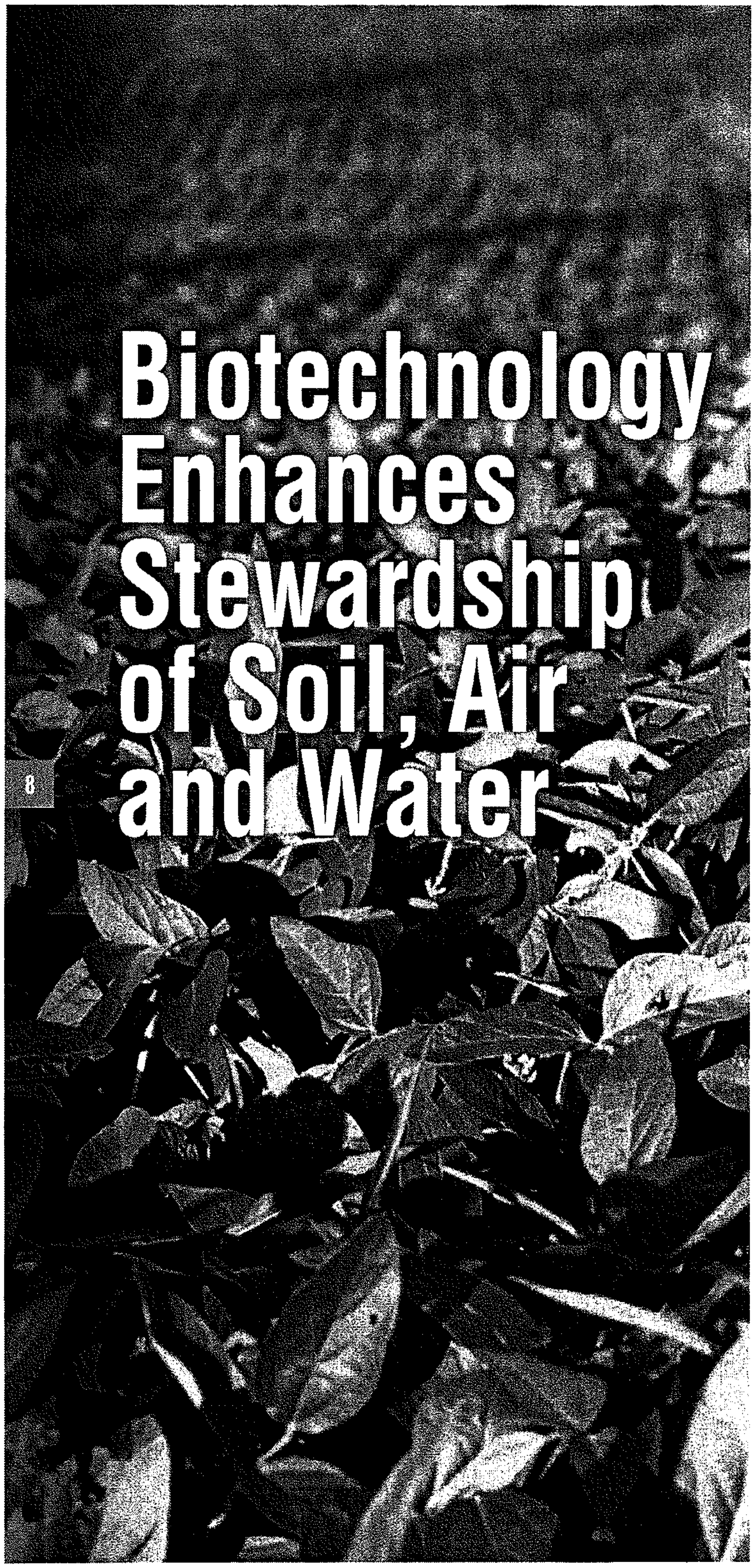
Similarly, corn growers planted 85 percent of their acreage, or 74 million acres, to biotech-derived corn in 2009. Seventeen percent of the corn acres were planted to Bt corn, 22 percent was herbicide-tolerant only, and 46 percent contained stacked traits (Fernandez-Cornejo, 2009).

Rapid Growth in Adoption of Genetically Engineered Crops Continues in the U.S.



Data for each crop category include stacked varieties with both HT (herbicide-tolerant) and Bt (insecticide-producing) traits. Source: USDA NASS (2009).

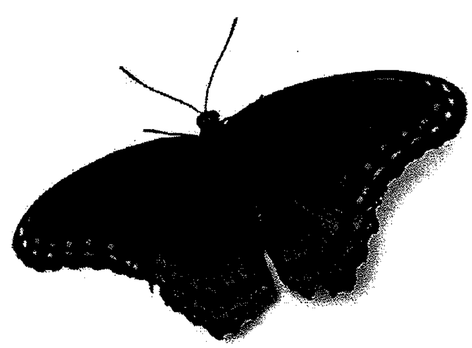
Biotechnology Enhances Stewardship of Soil, Air and Water



Sustainability is a key concept in agriculture. It is a multi-faceted term that refers not just to the ability of a field to produce crops, but to maintain productivity while accomplishing a variety of ecological, economic and social goals as well. Building on the definition of sustainability used in the 1990 Farm Bill, and according to Gold (1999), those goals include:

- Satisfying human food and fiber needs;
- Increasing the resource use efficiency of energy, water, fertilizer, soil and other natural resources;
- Enhancing environmental quality and the natural resource base upon which the agricultural economy depends;
- Reducing pressure on habitat, forests and other land uses by increasing the productivity of farmland;
- Making the most efficient use of nonrenewable resources and on-farm resources;
- Integrating, where appropriate, natural biological systems and control mechanisms;
- Sustaining the economic viability of farm operations, and
- Enhancing the quality of life for farmers and society as a whole.

Ultimately, sustainability is achieved when farmers make choices that are beneficial both ecologically and economically, and increase the long-term efficiency of their operations. By increasing yields, making pest control simpler and more effective, and facilitating the adoption of no-till or conservation tillage, biotech crops contribute significantly to agricultural sustainability. The benefits accrue in the improvement of soil, air and water resources.



As society creates incentives for sustainability, farmers' ability to reduce erosion and build soil organic matter through conservation tillage also opens new economic opportunities. U.S. Department of Agriculture funding for environmental cost-share programs has increased steadily – from roughly $3 billion in 1990 to $5.6 billion in 2005 – directing billions of dollars annually to conservation-oriented members of the farm community (U.S. EPA, 2008). Emerging markets for carbon offsets and water quality trading credits show great promise to create new revenue streams for producers with the interest, skills and tools to adopt best management practices (BMPs) such as no-till farming.

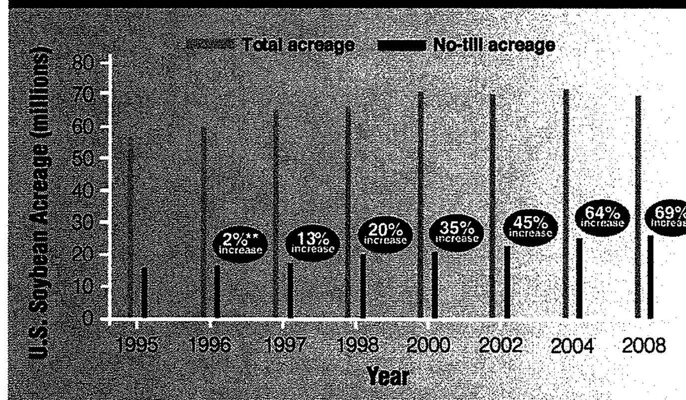
Biotechnology Facilitates Conservation Tillage

For millennia, farmers have tilled the soil to prepare seedbeds and control weeds, which compete with crops for nutrients, water and light, and can interfere with harvest. The advent of herbicides in the latter half of the 20th century allowed growers to combat weeds by chemical means, though pre-plant tillage and the use of post-emergence cultivation are still quite common.

The use of biotechnology to develop herbicide-tolerant crops was a breakthrough. Not only did it allow growers to simplify their weed control practices by using nonselective herbicides after crop emergence, but also those herbicides were so broad in their weed control spectrum and so reliable that pre-plant tillage was no longer necessary. The herbicide-tolerant crops made it far easier and less risky to adopt conservation tillage and no-till.

In 1995, the year before glyphosate-tolerant soybeans were introduced to the market, approximately 27 percent of the nation's full-season soybeans were no-tilled, according to the Conservation Technology Information Center (CTIC, 1995). The latest surveys by CTIC indicate that 39 percent of U.S. full-season soybean acres are no-tilled today, a phenomenon that closely tracked the adoption of herbicide-tolerant soybeans.

No-Till in U.S. Full-Season Soybeans*



Source: Conservation Technology Information Center (adapted from Johnson et al., 2007)
*Partially updated data: 2008 data from 2/3 of the counties in Iowa; 2007 data for Indiana and some counties in Virginia and Minnesota; 2006 data for Illinois, some counties in Missouri and Nebraska; 2004 data for the rest.
**Relative to 1995

In some states, no-till acres dominate the soybean landscape. For example, 69 percent of Indiana's soybeans were no-tilled in 2007 as well as 72 percent of Maryland's and 63 percent of Ohio's. Fifty percent of the soybeans in Illinois, 43 percent in South Dakota and 40 percent in Iowa were also no-tilled (CTIC, 2008).

Fighting Erosion

The growth of conservation tillage and no-till acreage has a significant impact on soil, water and air quality, which trace back to dramatic reductions in soil erosion. No-till farming can reduce soil erosion by 90 to 95 percent or more compared to conventional tillage practices, and continuous no-till can make the soil more resistant to erosion over time. In fact, Baker and Laflen (1983) documented a 97-percent reduction in sediment loss in a no-till system. Fawcett et al. (1994) summarized natural rainfall studies covering more than 32 site-years of data and found that, on average, no-till resulted in 70 percent less herbicide runoff, 93 percent less erosion and 69 percent less water runoff than moldboard plowing, in which the soil is completely inverted.

Conservation Tillage Definitions

The Conservation Technology Information Center (CTIC) has defined tillage systems according to the amount of crop residue left on the soil surface after planting and the type of tillage tools used. Reductions in erosion are proportional to the presence of crop residue on the soil surface (Shelton, 2000).

CTIC's definitions include:

Conservation tillage: Any tillage and planting system that covers more than 30 percent of the soil surface with crop residue, after planting, to reduce soil erosion by water. No-till, ridge-till and mulch-till are types of conservation tillage.

No-till: The soil is left undisturbed from harvest to planting except for planting and nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slots created by coulters, row cleaners, disk openers, in-row chisels or rotary tillers. Weed control is accomplished primarily by herbicides.

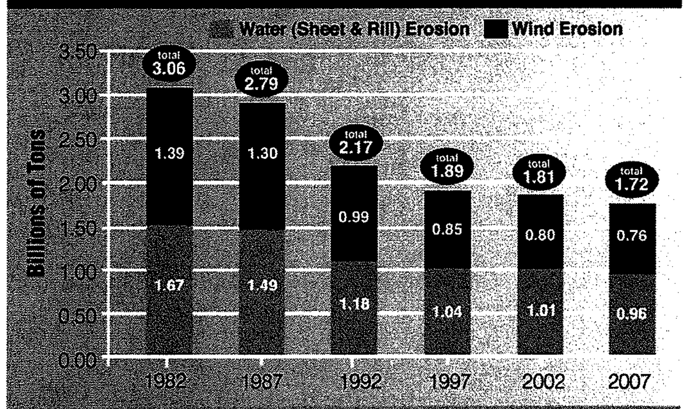
Ridge-till: The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed on a seedbed prepared on ridges with sweeps, disk openers, coulters or row cleaners. Residue is left on the surface between the ridges. Weed control is accomplished with herbicides and/or mechanical cultivation. Ridges are rebuilt during cultivation.

Mulch-till: The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps and blades are used. Weed control is accomplished with herbicides and/or mechanical cultivation.

Conventional tillage leaves less than 15 percent residue cover after planting. It typically involves plowing or intensive tillage. Tillage types that leave 15-to-30-percent residue cover after planting sometimes are referred to as **reduced tillage**, but they do not qualify as conservation tillage.

Continuous no-till: Maintaining no-till practices throughout the crop rotation cycle – avoiding the regular or periodic use of tillage – is called continuous no-till. The benefits of improved soil structure and carbon sequestration result from continuous no-till.

Erosion on Cropland by Year



Cropland includes cultivated and non-cultivated cropland. Source: USDA NRCS Natural Resources Inventory, 2010.

Despite the significant expansion of conservation tillage to date, erosion remains a tremendous threat to the productivity of the world's soils, as well as to the quality of water and air. Clearly, the opportunity to take highly erodible fields out of crop production and farm other soils more productively and with less soil loss will continue to be important sustainability goals.

When topsoil erodes – swept away by water or wind – it removes nutrients and well-structured soil from the field. That depletes the very layer of soil that is most hospitable to seeds and plants and sweeps away organic matter so valuable to soil health. It also results in the transport of sediment, pesticides and excess nutrients – especially phosphorus, which tends to be bound to the soil particles – to rivers, lakes and oceans, where they can disrupt natural ecological cycles. According to the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), an estimated 60 percent of the nation's total river-borne sediment is the product of erosion from agricultural fields (USDA NRCS, 1997).

Sediment clouds the water, reducing light penetration and reducing photosynthesis of submerged plants and algae. It can also clog the gills of aquatic organisms. Pesticides in streams and rivers can disrupt local plants, fish, macro invertebrates and other organisms.

Excess nutrients can cause algal blooms that in turn disrupt natural vegetation or even deplete the water of the oxygen needed by local aquatic communities to survive. In its 2004 National Water Quality

Inventory, a report to Congress, the U.S. Environmental Protection Agency (EPA) stated that sediment was the number-one pollutant in American rivers and streams, followed by bacteria, then organic enrichment/oxygen depletion (U.S. EPA, 2004).

Andraski et al. (1985) compared losses of three forms of phosphorus in runoff from four tillage systems – no-till, chisel plowing, strip-till and moldboard plowing. No-till reduced losses of total phosphorus by 81 percent; conservation tillage with a chisel reduced total phosphorus run-off by 70 percent and strip-till reduced it by 59 percent compared to moldboard plowing. Baker and Laflen's (1983) study compared total phosphorus losses between no-till and conventional tillage and found that no-tilling soybeans following corn reduced phosphorus loss in the soybeans by 80 to 91 percent compared to conventional tillage. They also found that no-till corn following soybeans resulted in an 86-percent reduction in soil loss, which in turn led to a 66-to-77-percent reduction in the loss of phosphorus.

Results of this type illustrate conservation tillage and no-till are extremely useful practices for reducing nutrient loads in surface waters – a fact being employed in water quality trading programs discussed later in this document.

Crop residue left on the soil surface by no-till or conservation tillage practices can significantly reduce topsoil erosion by wind. Crop residues reduce wind velocity at the soil surface, and trap soil particles to stop their movement (Lyon and Smith, 2004). Covering 30 percent of the soil surface reduces soil loss to wind erosion by 70 percent compared to bare soil, and 60-percent residue cover reduces wind erosion by 90 percent, according to Lyon and Smith (2004). Increasing the size of soil aggregates – one of the benefits of conservation tillage and no-till – also limits the ability of wind currents to lift soil and begin the cascading effect of erosion (Lyon and Smith, 2004). Compared to cereals, soybeans are not a high-residue-producing crop, but their residue can contribute to soil protection, and they play a major role in the agronomic and economic viability of crop rotations that include conservation tillage, the planting of higher-residue crops, and cover crops.

The airborne dust caused by wind erosion is a public health hazard as well as a highly destructive force. As it depletes cropland of its most precious resource, wind erosion can also cause other economic damage, such as sediment deposits in ditches and soil drifts across roads and railroad tracks, which are costly to remove.

The economic costs associated with wind erosion have not been as well-quantified as those of water erosion (Tegtmeier and Duffy, 2004). However, calculations by Tegtmeier and Duffy of the maintenance and infrastructure costs incurred in the U.S. to deal with water-borne sediment from cropland reveal a significant economic burden caused by erosion. Iowa State University researchers determined that clearing roadside ditches and irrigation canals of sediment from cropland costs $268 million to $798 million per year; the total annual costs to the nation's reservoir system from reduced capacity and dredging range from $241.8 million to $6.0 billion (Tegtmeier and Duffy, 2004). Reducing soil erosion through conservation farming practices, with risks and costs borne largely by farmers themselves, thus has clear impact on the nation's economy that extends beyond the loss of capacity on individual fields.

Rebuilding Soils

Topsoil is formed in a very slow process of physiochemical transformation of parent material and organic matter. Topsoil is the most fertile layer of soil, and can range from mere inches to many feet deep. Within the topsoil is a complex ecosystem of uncounted species of arthropods, nematodes, fungi, bacteria, actinomycetes and other microbes, as well as the compounds on which they feed.

Soil organic matter is the principal measure of the living portion of topsoil. Scientists categorize soil organic matter in three fractions:

- The living fraction, which includes the microbes, insects, microathropods, animals, and plants. Many of these organisms are beneficial, and may play a role in suppressing pathogens or enhancing plant health, resulting in a hardier, more pest-resistant crop (Gugino et al., 2009).

- Active organic matter, which includes the sugars, proteins and cellulose from dead plant, arthropod and microbial tissue that nurture the living fraction. It also includes sticky exudates from microbes and roots that bind soil particles together in aggregates that typify healthy soil.
- Humus, the dead, stable fraction of soil organic matter. Humus aids in the storage of nutrients and water, the deactivation of toxic chemicals, and stabilizing soil aggregates, but it is not a food source for microbes.

Soil flora and fauna thrive in conservation tillage conditions, generally increasing the level of soil organic matter and encouraging greater aggregation of soil particles. Between the small clumps of agglomerated soil are macro pores, or relatively large spaces, that aerate the soil, stimulating microbial-mediated mineralization of nutrients and allowing moisture to enter the soil through capillary flow. Cracks formed during weather changes, root channels and earthworm burrows provide conduits for water to enter the soil quickly.

Healthy, living soil with good structure can repair compacted layers formed by traffic or tillage over time. By contrast, soils with plow pans or other man-made compacted layers, or soils made shallow by erosion, leave crops more susceptible to fluctuations in the weather, such as drought or flooding (Gugino et al., 2009).

U.S. cropland soils have the potential to sequester 75 to 208 million metric tons of carbon equivalent per year.

Lal et al. (1998)

Years of conservation tillage rebuild soil organic matter as crop residues are steadily broken down in the upper inches of the soil by a healthy community of soil microbes, as well as macro invertebrates such as earthworms and insects. Reicosky and Lindstrom (1995) found that organic matter increased by as much as 1,800 pounds per acre per year in long-term no-till studies. In fact, a combination of no-till and cover crop management in corn fields derived from former grasslands or forests can yield higher levels of soil organic matter than the original grasslands or forests would have had they been left undisturbed (Kim et al., 2009).

Blanco-Canqui and Lal (2007) examined the impact of removing various amounts of corn stover on soil organic carbon in three different Ohio soils. They found that in two silt loam soils, the amount of stover removed from the soil surface was inversely proportional to the amount of new soil organic carbon that was produced during the 2.5-year study period. Complete removal of stover resulted in a 1.95 mt/ha (0.87 ton/acre) reduction in soil organic matter (Blanco-Canqui and Lal, 2007). They suggest that the study's clay soil, in which the organic matter did not respond significantly to the removal of stover, may offer a challenging environment to microbes, and be at or close to its saturation level for soil organic carbon, a stable state slow to react to stover removal.

Reducing Agriculture's Carbon Footprint

Conservation tillage and no-till can reduce greenhouse gas emissions in a number of important ways, including:

- Capturing atmospheric carbon in healthy, no-tilled soils and converting it into soil organic matter, a process called carbon sequestration. If the process is continued for years, that organic matter becomes a stable sink for carbon.
- Lowering fuel consumption and the emissions from it.
- Reducing the application of nitrogen, much of which is made from fossil fuels (and applied with fossil-fuel-burning equipment), improving the carbon footprint of agriculture and the nation as a whole.

Viewing those reductions individually and together shed light on opportunities to contribute to a reduced carbon footprint through conservation tillage, an ecologically sustainable practice made more economically viable with the help of agricultural biotechnology.

Carbon sequestration. Sequestering carbon on cropland is one of the most attractive carbon offsets in agriculture's portfolio. In fact, Lal et al. (1998) estimate the capacity of U.S. cropland soils to sequester carbon at 75 to 208 million metric tons (83 to 229 short tons) of carbon equivalent per year – 24 percent of the emissions reduction assigned to the U.S. in the Kyoto Agreement.